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14. ABSTRACT
As part of this effort, REMUS UUVs from Cal Poly and SIO jointly collected CT profiles around the model boundary (see below), and in and around the Tijuana River plume before, during and after storm events. Data were collected in February and March of 2008 and 2009 for a total of 15 missions. These observations were then used by the model for initiation and validation. The DELFT-3D FLOW model is now operational and can be run to evaluate the impact of river flow in the coastal area of interest. Results have quantified sensitivity of the plume trajectory to wind and heating.

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Hydrodynamic Modeling, Unmanned Underwater Vehicles, Source Characterization, Coastal Oceanography

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OBSERVATIONS AND MODELING FOR SOURCE CHARACTERIZATION

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LONG-TERM GOALS

Our work is focused on coupling Unmanned Underwater Vehicle (UUV) and other coastal observations with a 3D hydrodynamic model (DELFT-3D FLOW) to investigate circulation and transport of coastal source material. While coastal areas near riverine discharge have traditionally been difficult to sample, UUVs with advanced sensor technology afford the opportunity to systematically study the dynamic components of these systems. Highly resolved measurements of circulation patterns, in water components, bottom topography and characterization will be coupled with the modeling effort. This combination will allow UUV guidance and improve model performance. It is hoped that the integration of mobile systems for localized modeling will be a 'system' that is portable to other systems to help advance our understanding of circulation patterns and mechanisms for change in bottom topography and morphology.

OBJECTIVES

The primary goal of this study was to develop a high resolution predictive capability of terrigenous source material and its advective transport within the Gulf of Catalina and along the shoreline of San Diego County. This was achieved using a combination of in situ observations and a 3D hydrodynamic model (DELFT-3D FLOW). Source characterization was conducted using a number of UUVs equipped with appropriate sensors. These sources include riverine inputs from the Tijuana River and two outfall plumes in the region. The UUVs were also deployed to observe the behavior of these sources in space and time. Data from UUV platforms and other components of an observatory network in the area helped populate the model for initialization, evaluation and optimization of predicting the advective flow of these sources of interest. The interaction between model and observational assets continued throughout the program ensuring optimization as well as providing guidance for UUV mission planning. Work to include a watershed module with the intention of better quantifying riverine inputs into the local area is ongoing.

APPROACH

Environmental Observations with UUVs: As part of this project, observational data sets on regional and local fine scales were collected by REMUS UUVs. Cal Poly owns and operates two REMUS vehicles with 5,300 km of underwater time and over 250 missions. These deployments have included conditions similar to the AOI for this study; river plumes, surf zone transition areas, dye plumes and outfall plumes. For a description of the vehicles and their applications see Moline *et al.* (2005, 2007, 2010). The sensor suite on these vehicles was used to characterize various sources in the region and track their behavior in time and space. These data were integrated with the model for improved parameterization of the model and predictive power (see Hibler et al., 2008). Additional observations in the area were also used to supplement the UUV data for the modeling effort (see below).
Delft Model: A three-dimensional circulation and transport model DELFT-3D FLOW was used in this study to predict the advective transport of sources within the study area in Southern California. Tidal, wind-driven and density-driven circulation were all accounted for in the model. The effects of bathymetry, earth's rotation and bed stress were also included. The model is based on the continuity equation and horizontal momentum equation and uses a turbulence closure submodel to adjust mixing rates as function of flow conditions. The model domain is represented by an orthogonal curvilinear mesh in the horizontal and a terrain following ($z-$) coordinate system in the vertical. The model numerics are fully documented in WL Delft Hydraulics (2003) and it has been used to conduct various modeling studies (*i.e.* Hesselink *et al.* 2003; Bielecka and Kazmierski 2003). The model mesh was developed based the best bathymetry information available that provide comprehensive coverage within the study area. In addition, larger scale model output (Southern California NCOM) was used to provide boundary information to the plume resolving higher resolution mesh. For example, the Tijuana River mouth, two outfall locations as well as beach locations were of interest to ONR. The circulation within the finer resolution model was driven by flow (astronomical tidal predictions and NCOM currents, temperature and salinity). The 44 vertical layers were used to achieve resolution required and computational considerations.

WORK COMPLETED

UUV observations: As part of this effort, REMUS UUVs from Cal Poly and SIO jointly collected CT profiles around the model boundary (see below), and in and around the Tijuana River plume before, during and after storm events. Data were collected in February and March of 2008 and 2009 for a total of 15 missions. These observations were then used by the model for initiation and validation. See http://www.marine.calpoly.edu/auv/REMUS/index.php for Cal Poly deployments. Additional observations for the model included HF radar for surface currents, River drifters that were used for multiple deployment (Centurioni), Tijuana River flow data, wave data from the CDIP buoy array, Imperial Beach buoy (ADCP/T-chain), and meteorological data from land and offshore buoys.

Development of a model for the California coast adjacent to the Tijuana River and San Diego Harbor: A model was developed for the area of interest. Battelle received Southern California NCOM results from UCSD for the period 1/1/2009 to 3/31/2009. These results were requested to provide boundary conditions to the Delft3d-FLOW (version 4.00.003.438M) model applied to the coastal region near the Tijuana River to simulate the three-dimensional circulation around the mouth of the Tijuana River, the open coast and the San Diego Harbor. Battelle collaborated with Deltares to process the NCOM results into forming initial and boundary condition inputs for this finer scale model (Figures 1). The computational mesh consisted of 106 x 166 cells in the horizontal and 44 z-layers. The computations were carried out using universal transverse Mercator coordinate system with the Coriolis parameter set to be consistent with the 33 degree North latitude. The computation mesh had an alongshore extent of about 75 km and a cross-shore extent of about 40 km. Depths ranged from a few meters to over 1300 meters. The simulation time step was one minute. A simulations was done using 30 second was done that reveal unappreciable differences with the larger time step.

The model was configured to include the transport of heat, salt and a dye which tagged Tijuana River water. Wind speeds, relative humidity air temperature and cloud cover were provided by the NAM model with 2.0-km spacing every 3 hours. NCOM model results were provide in three hour intervals and supplied to the plume model as part of the Riemann boundary conditions. The model was driven with astronomical tidal flow plus the currents from NCOM.

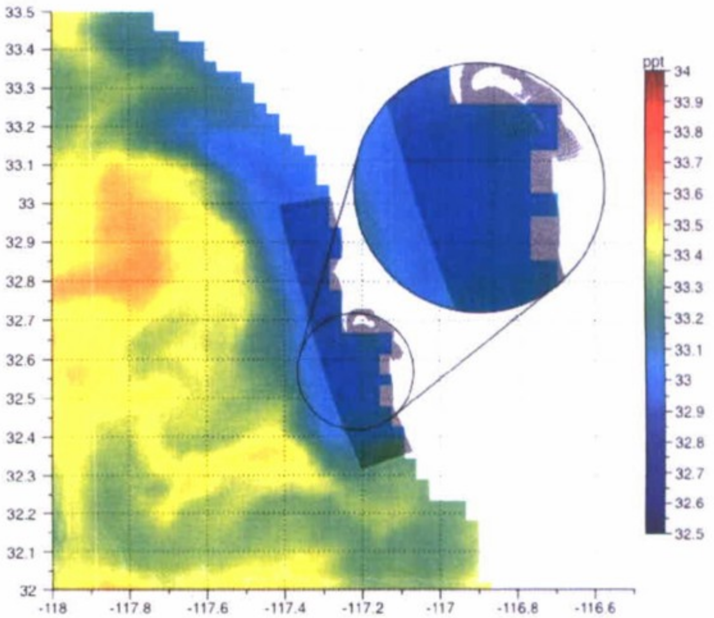

Figure 1. The NCOM modeled surface salinities for midnight February 1, 2009 are shown. The Delft3d-FLOW plume mesh and that portion of the NCOM results that are directly used to define boundary conditions for the Delft3d-FLOW model are overlaid. A time series of the NCOM results are used to supply boundary conditions to the Delft3d-FLOW model; this figure shows one NCOM snapshot with additional detail.

RESULTS

The plume model was applied to February 2009 boundary conditions supplied by the Naval Coastal Ocean Model (NCOM) for currents, water temperature and salinity as boundary and initial conditions and the NAM model for the meteorological forcing as configured by Deltares. Under this program we are evaluating the sensitivity of the numerical parameters (time step, eddy viscosity and diffusivity) and meteorological processes on the estimates of the hydrography within the Southern California Bight at the Tijuana River plume scale. Figure 2 illustrates the sensitivity of the near surface water temperature to four cases, clearly showing the model sensitivity to wind in particular.

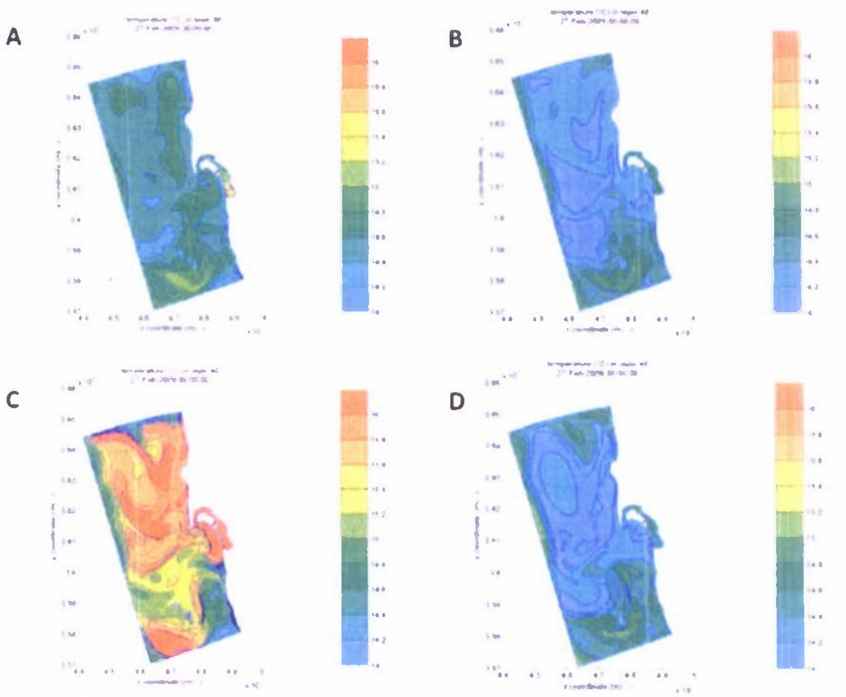

Figure 2. The Delft3d-FLOW modeled surface temperatures for midnight February 27, 2009 are shown under four run conditions. A) The base case with NCOM and NAM forcing. B) The no-wind case with NCOM and partial NAM forcing. C) The no-heat model case with NCOM and partial NAM forcing. D) The no wind or heating case with NCOM forcing.

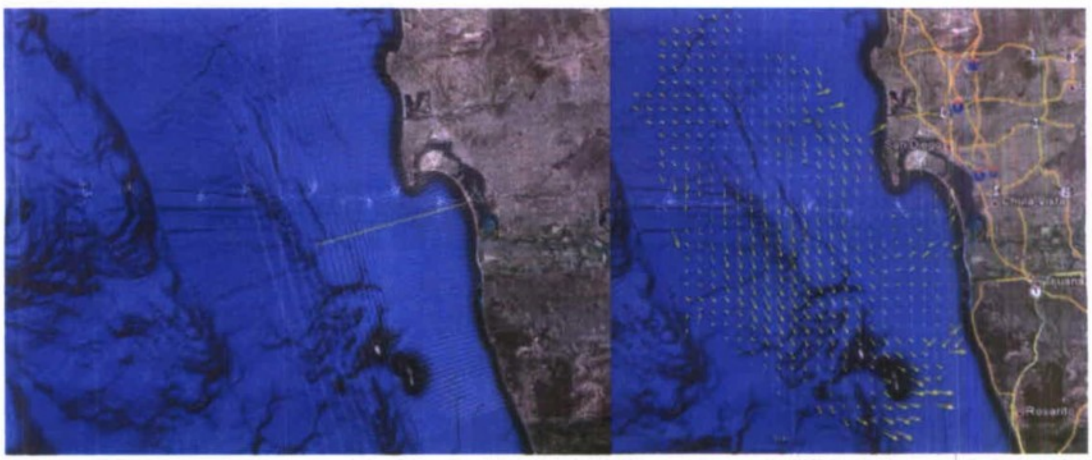

Figure 3. (left) Surface flow modeled by Delft3d-FLOW mesh and NCOM for midnight February 27, 2009. (right) The measured surface currents for the same time interval along San Diego. The 25km transect line in left panel shows the location of the vertical slices made in Figure 5.

Figure 3 shows the derived surface currents associated with the same day as in Figure 2, with the transect line for the vertical data slices produced by the model (see below). This transect was selected to be approximately the location of the UUV deployments conducted in January 2009. Flow is generally to the south transitioning to offshore along the outer boundary. The nearshore currents south of the opening of San Diego Bay show a northerly propagation resulting in an eddy off of Point Loma. The currents around the Tijuana River mouth show a weak offshore flow. The measured currents for this hour also show the same southerly flow with an eddy off of Point Loma and weak currents along the Tijuana River mouth (Figure 3).

The transport and mixing of Tijuana River discharges were simulated for a February 2009 flow event. The base case, no wind stress, no surface heating, and neither wind nor surface heating cases were simulated to evaluate the models sensitivity to the processes as they effect transport. During this period, the discharges of the Tijuana River was between 0.1 and 2.5 m^3/s; a nominal dye concentration of 1 units/m^3 was added to the discharge. Figure 4 shows the surface water concentration of the dye when released from the Tijuana River under the same four conditions as illustrated in Figure 2. Although surface heating does impact the simulated trajectory, for these conditions, wind forcing appears to play a larger role in the trajectory of the Tijuana River plume. Specifically the partial NAM forcing appears to mix the plume less and allow higher surface concentrations to propagate westward.

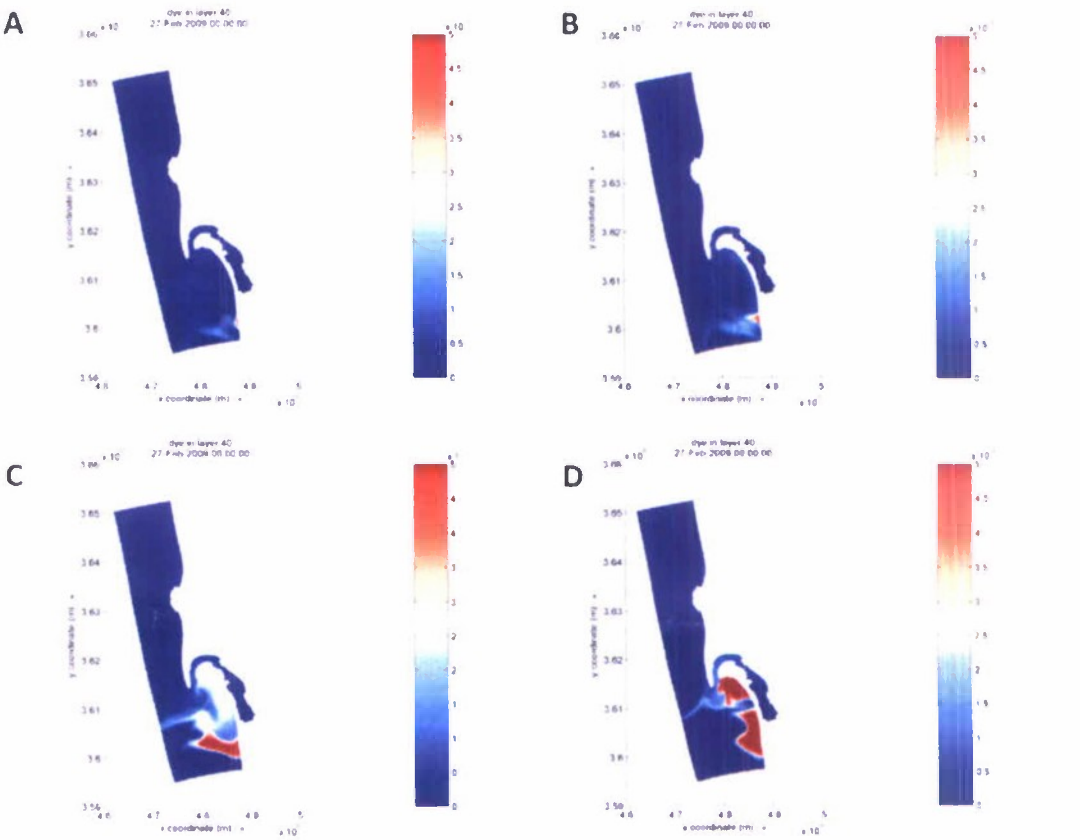

Figure 4. The Delft3d-FLOW modeled surface dye concentrations ejected from the Tijuana River for midnight February 27, 2009 are shown under four run conditions. A) The base case with NCOM and NAM forcing. B) The no-wind case with NCOM and partial NAM forcing. C) The no-heat model case with NCOM and partial NAM forcing. D) The no wind or heating case with NCOM forcing. Values in excess of 0.005 units/m^3 are not distinguishable in order to more clearly show the larger horizontal scale plume features at the lower end of the concentration range.

Vertical sections of the model runs shown in Figure 4 are shown in Figure 5. Dye concentration for the upper portion of the water column along the transect (see Figure 3) are shown for each of the four simulations. Along the transect, the plume is about 5 km offshore and mixed to a depth of about 15 m and is 10 km wide for the base case (Figure 5A). In the case without wind forcing but including surface heating (Figure 5B), the plume remains attached to the shore and mixed to a depth of about 10 m and 15 km wide. For both of these cases, the plume remains as one water mass. When winds are applied but not surface heating is included, is about as deep as the base case but is divided into a shore-attached and an offshore portion. For the final case without wind or heat, the plume is again divided but not as deeply mixed as when wind is applied (Figure 5D).

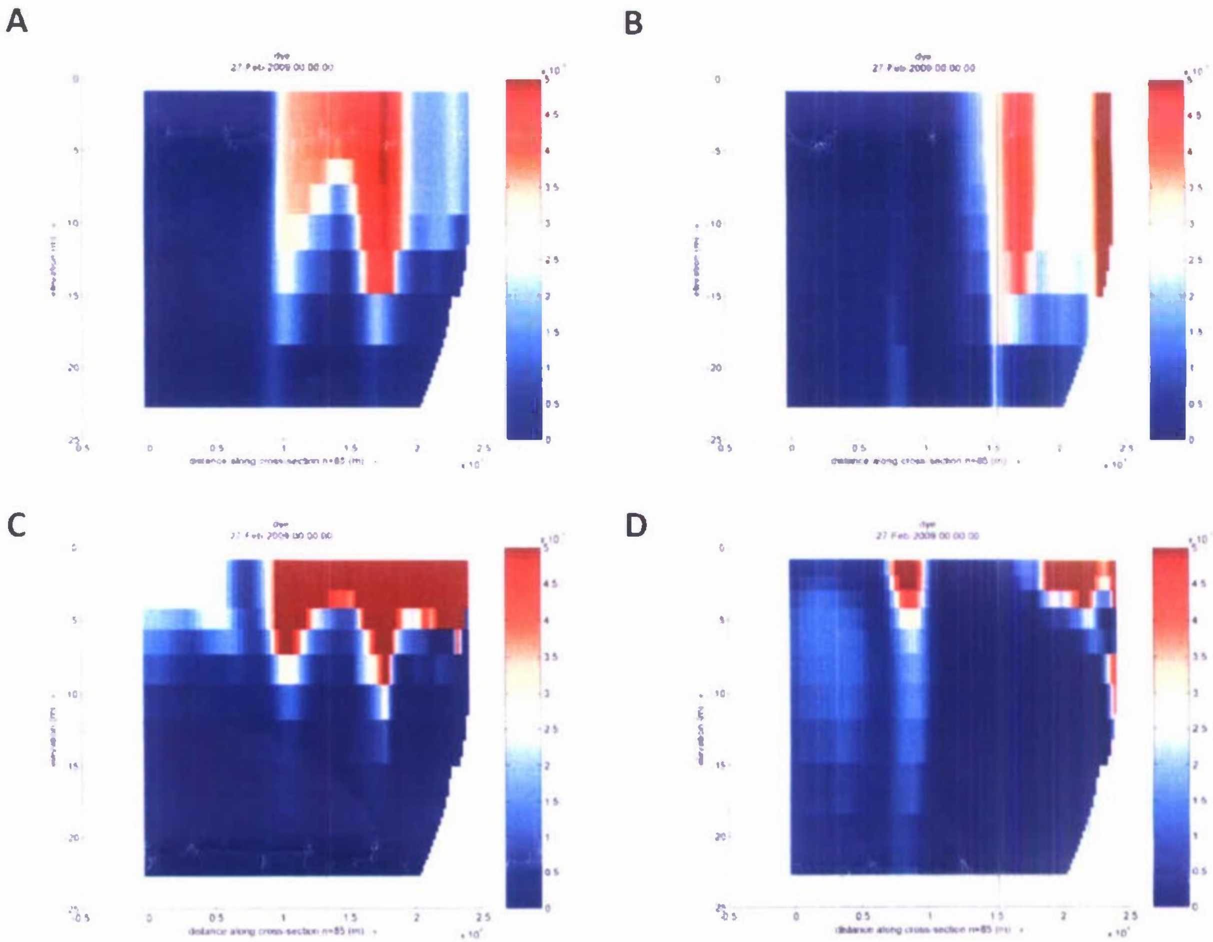

Figure 5. The Delft3d-FLOW modeled vertical distribution of dye concentrations ejected from the Tijuana River for midnight February 27, 2009 are shown under four run conditions. A) The base case with NCOM and NAM forcing. B) The no-wind case with NCOM and partial NAM forcing. C) The no-heat model case with NCOM and partial NAM forcing. D) The no wind or heating case with NCOM forcing. Values in excess of 0.005 units/m^3 are not distinguishable in order to more clearly show the larger horizontal scale plume features at the lower end of the concentration range. The vertical sections shown here are along the transect shown in Figure 3.

The DELFT-3D FLOW model is now operational and can be run to evaluate the impact of river flow in the coastal area of interest. A meeting of all involved collaborators is scheduled for June, 2011 to further evaluate the model and generate a group publication from the effort.

IMPACT/APPLICATIONS

These data will advance our understanding of the forcing mechanisms governing the temporal and spatial flow regimes of land-ocean margins and riverine outlets environments, provide a benchmark data set for testing a hydrodynamic model, and provide operational guidance for conducting UUV surveys in regions of complex flows and topography.

TRANSITIONS

None to date

RELATED PROJECTS

This collaboration originated from work done in ONR's Coastal Environmental Effects program (N00014-06-2-0105) and a data-model re-analysis program (N00014-07-1-1113). Work combining these approaches continues on reef and atoll systems (N00014-10-1-0524).

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HONORS/AWARDS/PRIZES

Mark A. Moline, named lifetime Senior Fellow - California Council on Science and Technology 2008
Mark A. Moline, recipient of a Fulbright Chair Scholarship Award 2011